Metallurgical Waste Recycling for Transport Construction

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Abstract. Nowadays industrial waste recycling is the key concern for metal industry. Higher steel outputs are accompanied by increased by-products related with steel production. One of large-tonnage by-products of metallurgical production is electric arc furnace dust from arc steel furnaces. The use of metallurgical waste is therefore a promising area of research. The chemical composition of dust from arc steel furnace cleaning has been studied. The microstructural features of gas cleaning dust have been investigated. Dust formation processes have been understood. The most efficient dust clotting schemes have been selected. It has been demonstrated that it is possible to granulate dust using process water as a liquid-phase binder. It has been established that a disk pelletizer makes it possible to obtain granules up to 5 mm in diameter with sufficient strength for their transportation and further drying. When using a screw extruder it is possible to produce granules of proper cylindrical shape. Heat released from hydration of free CaO being a part of dust and bulk mixing result in screw conveyor jamming and die hole clogging. Bulk dust density has been determined for gas cleaning of arc steel furnaces. Bulk density of granules obtained by two granulation methods has been determined - with the use of a disk petellizer and a screw granulator.

Keywords: Electric arc furnace dust · Microstructure analysis · Waste granulation

1 Introduction

Waste generation in the metallurgy industry results in technogenic deposits [1, 2]. In Russia annual steel production is approximately 70 mln tonnes of steel, of which 22 mln tonnes count for electric furnace steel. Dust generated in electric arc furnace (EAF) can reach up to 30 kg per 1 ton of steel. EAF systems annually capture about 650,000 tonnes of electric furnace steel-making dust, with 99% gas purification ratio. Due to the negative impact produced by dust on the environment and human health it is essential to reduce dust generation and to develop dust reclaiming technology [3, 4].

Recycling of waste, in particular, dust, makes it possible to improve significantly production efficiency both by manufacturing additional core products and by making a new derivative product which is a recycle used to reduce consumption rates of raw materials and energy resources [5, 6]. The next step in the development of technologies

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for disperse waste and mineral residues storage is disperse waste pelletizing and its subsequent warehousing [7, 8]. Unlike a particulate form the pelletized material helps to avoid during dump storage air pollution due to dust emission and to reduce or completely exclude water pollution due to waste discharge. A pelletized product is easier to handle and it is less problematic to take it from the storage place. Thus, pelletizing makes better conditions for waste disposal and increases specific material consumption for storage areas (dumps and landfills). The development and introduction of pelletizing technologies for such disperse metallurgical waste as EAF dust makes it possible to optimise waste warehousing and storage, including further returnability to the production process.

2 Methods and Materials

EAF dust samples from EAF at the Oskol Electrometallurgical Plant with a bulk density of 0.67 g/cm^3 were taken to investigate the physical, chemical and process properties. The chemical composition of the taken samples is shown in Table 1.

Table 1. Chemical composition of EAF gas cleaning dust.

Name	Oxides content, %											
	CaO	SiO_2	$F_{e2}O_3$	MgO	Al_2O_3	MnO	Cr_2O_3	P_2O_5	ZnO	SO_3	K_2O	Na_2O
EAF dust	10.87	6.51	54.64	4.35	0.48	2.33	0.35	–	3.85	1.16	6.19	8.05

The chemical composition of the material samples used was determined with the ARL 9900 WorkStation series X-ray fluorescence spectrometer with integrated diffraction system. Scanning electron microscopy (SEM) was carried out to study the constitution and structure of particleboard EAF dust. The research was carried out on a high resolution scanning electron microscope TESCAN MIRA 3 LMU. The fraction distribution of particles in the investigated material compositions was studied on the ANALYSETTE 22 NanoTec plus laser particle size analyzer. Bulk density was determined in accordance with GOST 19440-94 Metal powders. Bulk density determination. Part 1. Funnel method.

Experiments were carried out on a laboratory disk pelletizer using water as a binding liquid to produce a finely dispersed spray through the pneumatic atomiser nozzles. The use of water as a binding liquid is due to the nozzle design features and the impossibility of obtaining a fine spray on solutions with a higher density and higher viscosity. A laboratory disk pelletizer (500 mm diameter and 300 mm height) was loaded with 2–3 kg of EAF dust. Water was injected onto the material movable layer through a pneumatic spray nozzle. After the embryos formation (granules measuring 1 ÷ 2 mm), dust was added to the material wet moving layer which led to the granules growth. After the granules had stopped growing, water was injected to lubricate the layer and again granule growth powder was added. Repeating these operations many times, they received granules of the required size up to 5 mm, which were transferred over plate board into a receiving container. The granules received were dried in a drying cabinet at 105 °C for 24 h. The humidity was determined by drying to a constant mass. Granulation assessment was carried out visually. In order to assess the granular fraction percentage yield, the granules were scattered using the sieve method. Fractions calculation was assessed by sieved substance weight. Humidity was determined by drying in a drying cabinet at 105° C to a constant weight; the strength of wet granules (after the granulator) was determined by dropping them from 1 m height on a steel surface by the undestroyed granules yield percentage.

Experiments were also conducted on a laboratory screw extruder to produce cylindrical granules. The screw used had a diameter of 60 mm in 40 mm increments (in the moulding area) through a flat die (3 mm thick, 54 holes with a diameter of 3 mm). Screw speed is 30 rpm. By changing ratio between liquid-phase binder and powder, we achieved quality granules. The optimal ratio of liquid and solid products in the mixture was fixed, whereby quality granules were obtained during the pelletizing process. The quality of the granules received (granule side surface condition, harness flow uniformity from the die holes) was determined visually. The granules obtained were analysed for humidity by drying the sample to a constant weight in a drying cabinet at 105 °C.

3 Results and Discussion

Dust Microstructure. Steelmaking dust microstructure is shown in Fig. 1. Dust particles shape is determined by their origin. The particles generated by evaporation and oxygen blowing of bath have a shape close to spherical, which is due to droplets excess surface energy and relatively low force of gravity acting on the droplet [9, 10]. This is common in liquid dispersion or droplet vapours condensation. Electric furnace steelmaking dust tend to be generated at the fogging stage when during coalescence micro droplets run into one another and newly form a ball-shaped drop. The average droplet size is 1.5–2.5 μm and corresponds to the highest peak on particle size distribution histogram (Fig. 2).

However, in dust, there is a large number of irregularly shaped particles, spherical particle colonies sticking together. This happens when the colliding droplets consist of very viscous liquids and merging process into one spherical drop is slowed down, only the colliding droplets stick together. These “incorrect” particles also have a normal density, equal to the substance density from which they were derived. These conglomerates are 10–12 μm in size and correspond to the third peak on particle size distribution histogram.

These microphotographs also show loose particles of various shapes, so when metal vapour condensation occurs simultaneously with normal density particles, the density of which is much lower than that of metal.

For the dust generated during charging materials loading, i.e. condensate, dust particles will be sharper and more irregularly shaped [9, 10]. In addition, crystalline particles were found. Typically, the primary particles in smoke have the correct crystalline form, formed by direct transition of the vapour crystal. If smoke is produced by condensing vapour in the form of liquid droplets and then solidifying them, smoke

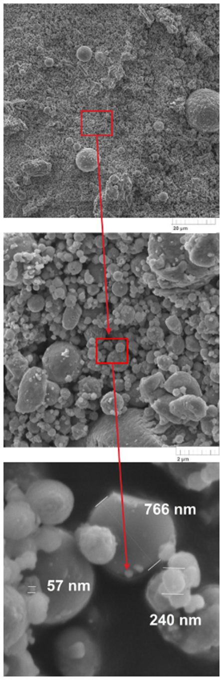

Fig. 1. EAF dust microphotographs.

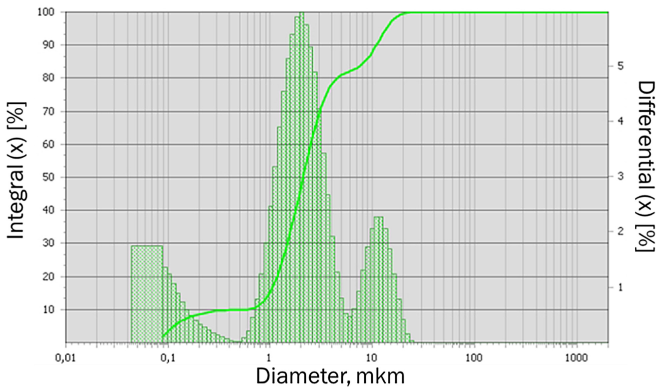

Fig. 2. EAF dust granulometry analysis.

particles may have both crystal and spherical shapes. A number of metal primary smoke particles and their oxides are small, their average size being less than 100 nm, which corresponds to the first peak on the particle size distribution histogram. Particles small size makes it difficult to determine their shape and average size.

EAF Dust Granulation. To work out metallurgical waste pelletizing methods, EAF dust was pelletized by the following two methods: with the use of disk pelletizer and screw pelletizer. The purpose of pelletizing was to produce spherical granules up to 5 mm in size from EAF dust. EAF dust pelletizing by pelletizing on a disk pelletizer to produce spherical granules from EAF dust is appropriate. Granules received had the correct spherical shape and the amount of water was 9–12% of dust mass. The high content of CaO (10–12%) quickly binds free water in a finely dispersed product, resulting in fine granules of 2–5 mm in size, which make up 80% of granules total number. Powder-shaped material is then rolled up problematically and coarse granules of 15–20 mm are formed as a result of fine granules adhesion and are spherical conglomerates. Granules with a size of 2–5 mm are optimal for future use. Granule fracture during the strength tests take place along the druse boundary. The amount of binder as well as other pelletizing process parameters have not significantly affected either structure or strength of granules. Granules humidity received is 6 ÷ 8%. After a strength test by granules dropping, 90–95% of them retained their shape and size. This allows granules to be transported directly after granulation to the dryer for dehydration. Dried granules bulk density was 1.44 g/cm^3. Installation of a pneumatic atomiser directly above the plate and a fine dust atomiser reduce the dust build-up during fine dust dispensing. The granulation rate was 40 kg/h.

For the screw type extruder, it was possible to establish an optimal ratio between liquid and solid phases during granulation. The harnesses were uniformly flown out of the die hole under 16–18% humidity. The side surface of the harnesses was smooth under this humidity. As the humidity increased, there was harnesses adhesion and water separation. When the humidity dropped, the dies were heated and the screw was jammed. During pelletizing of the optimum composition weighing more than 10 kg, there was considerable heating of the nozzles and pelletizer walls, which resulted in the screw jamming. Heating also results in a significant heat release when hydrating the free lime contained in the dust. Progressive lime also caused the mass to harden and stick to the screw and the granulator inner walls, as well as blocking the holes in the die matrix and the screw jamming. After a strength test by granules dropping, 93% of them retained their shape and size. This allows granules to be transported directly after granulation to the dryer for dehydration. Dried granules bulk density was 1.62 g/cm^3. The granulation rate was 15 kg/h.

The granules received are shown in Fig. 3.

a) b)

Fig. 3. Granules received a) Torsion type granulator b) Screw type granulator.

4 Conclusion

The analysis found that EAF dust is a heterogeneous material with three distinct particle size distribution zones. Stable material can be produced through granulation which requires less storage space: bulk density increases from 0.67 g/cm^3 to 1.44 g/cm^3 and 1.62 g/cm^3 for the disc pelletizer and screw type granulator, respectively. The use of process water as a liquid-phase binder is sufficient to produce granules with the strength needed to transport them to the drying unit. The cylindrical granules density is higher than the density of granules obtained by pelletizing; this is due to the emergence of compression in the dies moulding matrix working area. The production of cylindrical granules in large volumes is problematic; heat is generated by hydration of free CaO, which is part of the dust, and mixing the mass leads to screw jamming and dies clogging. The rational scheme is to use a disk pelletizer. Its pelletizing speed is 2.7 times higher than that of the screw pelletizer, which is due to the time it takes for the screw pelletizer to reach its optimum composition (water/solid phase). It would be advisable to carry out further research with granular material and use it as a stabiliser to produce road-building materials that can be used both in structural elements and in the earth bed of roads and railways.

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References

1. Bodyakov, A.N., Meshkova, K.V., Dukhovny, G.S.: Stabilization of metallurgical slug from arc steel-making furnaces. IOP Conf. Series: Mater. Sci. Eng. **945**(1), 012082 (2020)
2. Leontiev, L.I., Dubanov, V.G.: Technogenic wastes of ferrous and non-ferrous metallurgy and environmental problems. Ecol. Ind. **4**, 32–35 (2011)
3. Alpatova, A.A.: Investigation of the composition and properties of electric steelmaking dust and search for directions for its utilization. Physics and chemistry and technology of inorganic materials. pp. 322–323 (2016)
4. Alpatova, A.A.: Investigation of the processes of dust formation during arc heating of metal and the properties of dust for its utilization. Nauka, Moscow (2016)
5. Nevyantsev, G.I., Yurichev, A.V.: Development of installations for recycling dust from gas cleaners of metallurgical furnaces. Design Bureau **6**, 32–39 (2015)
6. Pugin, K.G.: Reducing the environmental burden of steelmaking through the use of fine iron-containing waste in metallurgy. Sci. Res. Innov. **4**(3), 64–71 (2010)
7. Sumarokova, L.S., Kapustin, F.L., Fomina, I.V.: Granulation as a method of utilization of pulverized fine-dispersed production waste. Energ. Res. Conserv. 452–455 (2016)
8. Smirnov, L.A., et al.: Modern technologies and equipment for processing and using technogenic waste of metallurgical production **34**, 69–78 (2017)
9. Belousov, V.V.: Theoretical fundamentals of gas purification. A textbook for high schools, Moscow (1988)
10. Khilko, A.A., Zubkova, S.V., Simonyan, L.M.: Studying the properties of electric steelmaking dust. News of higher educational institutions. Ferrous Metal. **7**, 68–69 (2010)